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HYDROUS PYROLYSIS OF DIGESTATE AS ALTERNATIVE TO POST COMPOSTING IN A BIOWASTE ANAEROBIC DIGESTION FACILITY

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Introduction

Biowaste definition, EU production and recovery options

- Biowaste can be defined as a mixture of vegetal and animal biomasses that are residues of human activities.
- In Europe, more than 118 millions of tons of biodegradable waste are produced each year; only 25% of this amount is collected and sent to the given recovery option.
- The recovery treatments are mainly based on biological processes: the most used is the composting composed by the integrated anaerobic/aerobic method.
- Although the composting is widely used, its sustainability is not always guaranteed because of long process time, large areas needed for storage and processing, environmental impact due to annoying odors released by diffuse and fugitive emissions other than a not favorable ratio between the value of the product (compost) and the cost of the process.

*Introduction*₂

*Biological recovery of
biowaste: value of compost*

- The main limitation of biological process is the low economic value of the compost obtained from biowaste coming from separate collection of municipal waste.
- This important source of biodegradable matter is often contaminated by other waste with a fraction between 10% and 25%, depending on the waste collection system adopted for the separation.
- The presence of this fraction, generally represented by plastics and metals, can further decrease the economic value of the compost that is sold at a price between 0 - 3€/ton.

Introduction₃

- An alternative to compost production is the transformation of the biowaste, including digestate, into different products, either solid, liquid or gaseous obtained by means of thermochemical treatments.

Thermochemical options for biowaste recovery

THERMOCHEMICAL CONVERSION						
	Torrefaction	Pyrolysis			Hydrothermal	Gasification
		Slow	Fast	Intermediate		
Temperature, ° C	~ 200 - 300	~400	~500	~500	~180 - 250	~800
Pressure, bar	Depends on feedstock and wanted products	-	-	-	High pressure, generally ~18-20	-
Solid name product	CHAR					
	CHARCOAL <i>if from wood, peat or some related natural organic materials.</i>					
	BIOCHAR <i>if obtained from biomass and addressed to agriculture use</i>					
	BIOCOAL <i>if obtained from agricultural waste</i>			HYDRO-CHAR		

Scope

- The scope of this paper is to evaluate which is the potential effect of integration between a typical anaerobic facility with an additional stage of hydrothermal carbonization of digestate.
- The HTC stage substitutes the aerobic process: the integration should be able to reduce the process costs, avoid the aerobic treatment that is time and space consuming and obtain a high-added value product, in a limited footprint. The evaluation is carried out by recurring to material, carbon and energy flow assessment.
- All data not specifically reported from the literature are on-site data taken at a facility having 33,000t/year biowaste capacity

DESCRIPTION of SCENARIOS

*The base-case scenario (real
facility)*

- The base-case is represented by a typical integrated facility where an anaerobic process is followed by an aerobic stabilization of the solid residue (digestate) in order to produce a raw compost.
- The anaerobic digestion is carried out by a dry-process in batch reactors, sequentially operated in order to have a semi-continuous operation. The correct level of moisture inside the reactors, that are not stirred, is maintained by feeding the leachate collected from the bottom of each reactor at the top of it. The recirculation of leachate allows to use only a part of this liquid waste that, in any case, constitutes an output of the process (30% of the waste inlet). After a residence time of 28 days, the digestate (48% of the waste inlet) is removed and undergone the aerobic stabilization in order to mineralize the carbon and obtain an inert substrate. The composted digestate is mechanically treated and dried in order to obtain a good soil conditioner.

DESCRIPTION of SCENARIOS⁻²

*The alternative scenario
(hypothetical)*

- The alternative system considers the substitution of the aerobic stage with a hydrothermal-carbonization process.
- The digestate flow is treated in a series of batch reactor able to treat in three cycles for day all the digestate produced by a given anaerobic digester.
- The expected benefit are:
 - the digestate converted into a mineralized substrate into one day instead of 45-60 days;
 - no need for compressed air and emission in the environment dramatically decreased;
 - healthier working space;
 - economic value of the hydro-char much more interesting than the compost value.

ASSESSMENT METHODOLOGY

*The application of MFA, SFA
and EFA to the scenarios to
be compared*

- The comparison between the two given scenarios has been performed by using the Material, Substance and Energy Flow Assessment (MFA, SFA, EFA) procedures.
- The basic data are referred to a real industrial plant for what concerning the base-case scenario and to the literature for data related to the hydrous-pyrolysis. A series of preliminary data coming from tests carried out on a bench-scale reactor has also been used (e.g. the water/digestate ratio, optimal temperature, etc.).
- The MFA and SFA procedures have been applied in order to quantify the mass balance of “good” flows and carbon content for the system under study. Energy content for each flow has been also obtained in order to study the partition of feedstock energy. The flows assessment has been realized by using the STAN software for three levels of detail: good (total mass and water), carbon and energy.

MATERIALS

- The biowaste of interest is the residue of anaerobic digestion of household biowaste collected by selected sources (restaurants, mall food courts, ...) and by domestic separate collection.
- This residue is known as digestate and represents the residue of a series of anaerobic reactions including hydrolysis, acid formation, methane formation.

The biowaste treated

Ultimate analysis, dry-basis	
C, % _{db}	38.0
H, % _{db}	4.8
N, % _{db}	0.56
O, % _{db}	20.3
Ash, % _{db}	36.0
Moisture, % _w	63.0

Table - Ultimate analysis of digestate from anaerobic digestion

RESULTS

The volatile solids constitute the 80% of the dry solids (33%) and the expected maximum yield of conversion into biological products is 26.4%; by assuming that anaerobic digestion has a biomass-to-substrate yield of 0.3, the expected amount of catabolic products cannot exceed 18%; the yearly mean value of produced biogas at the operating facility has a yield of 0.12 ton for each ton of fed biowaste with a composition of 60% (v/v) of methane, 40% (v/v) of carbon dioxide (dry basis); the moisture content is 5% (v/v).

A part of volatile solids is then converted into biogas while the other part remains in the solid state together with inert materials and water by forming the so called digestate. The amount of digestate results to be 58% of the initial biowaste.

The total mass balance over the facility boundary has been written by taking into account the data reported in the following. The biowaste input is 33,000t/y: biowaste contains about 12% of foreign material, that is in part separated up-stream the treatment and in part during the refining process of the raw compost. This waste content is not considered in the calculations.

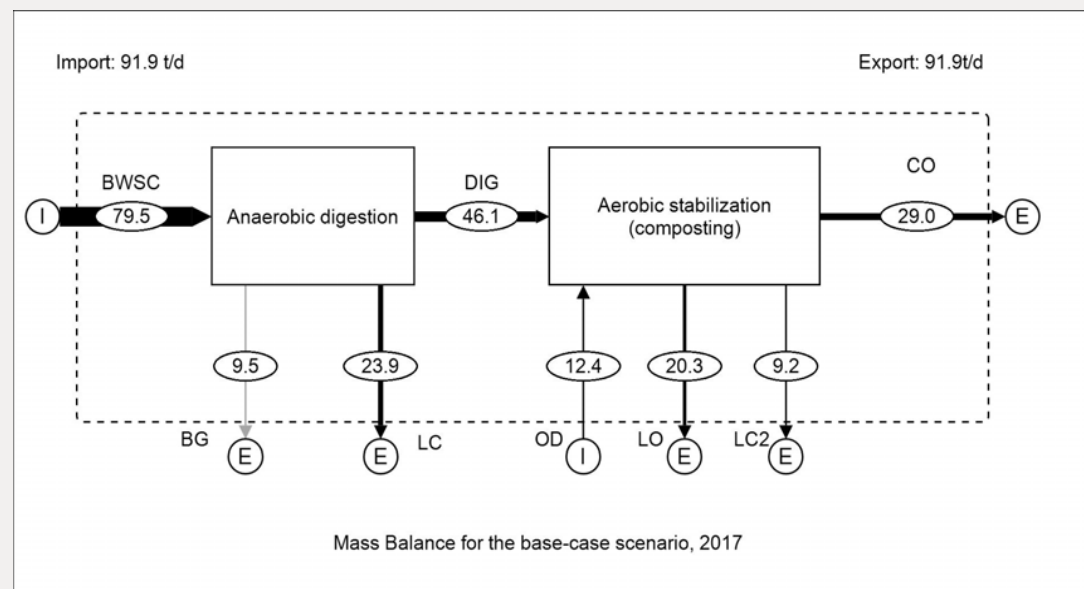


Figure - Total mass balance for the base case scenario

RESULTS₋₂

Digestate is aerobically treated in a further biological process in order to obtain compost. This process requires forced aeration for some weeks before obtaining a stable soil conditioner (compost). The amount of oxygen (OD) requested by the aerobic composting has been calculated by referring to the ultimate analysis of digestate by which the following reaction is obtained.



The oxygen stoichiometric demand for the digestate is $2.32\text{g}_{\text{oxygen}}/\text{g}_{\text{digestate}}$.

Actually, the real value is much larger than the theoretical one because of transport resistance inside the digestate bulk and the presence of nitrogen, since air is used. The facility uses $21\text{g}_{\text{air}}/\text{g}_{\text{digestate}}$ that corresponds to three times the air stoichiometric value.

The amount of raw compost is 36% of the biowaste.

RESULTS₋₃

The water balance can be really useful to follow its distribution in the various material flows. The moisture content of compost is 51% and it is generally lowered by drying until 25-30% to allow pelletizing and packaging.

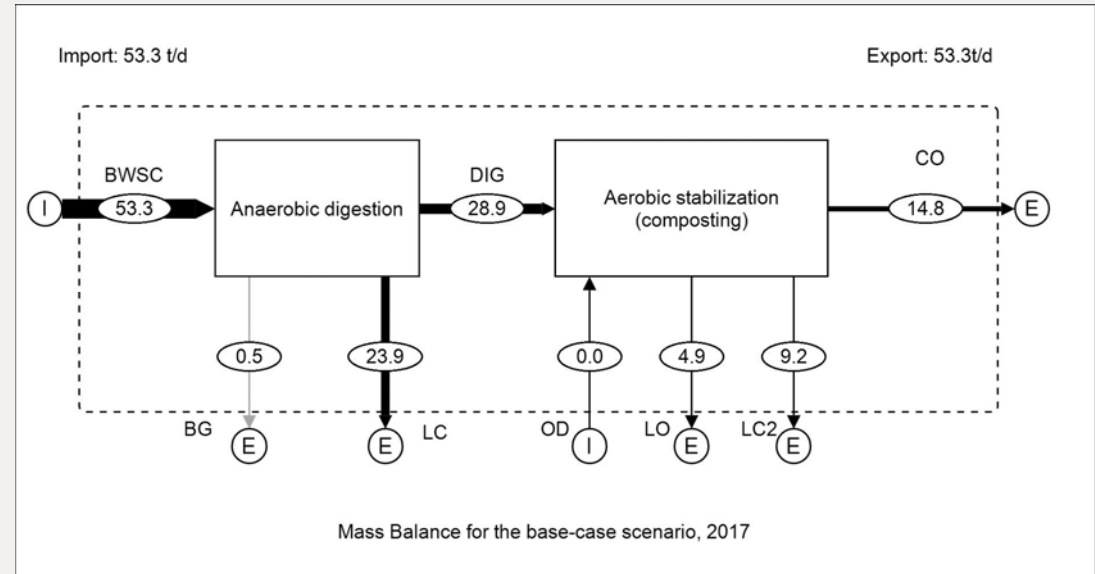


Figure – Water mass balance

RESULTS₋₄

The substance flow analysis has been carried out on carbon to give information about its partition along the different stages of the process in the gas, liquid and solid phases. The input data for the SFA are: carbon content in the biowaste equal to 48% (db) and carbon content in the digestate equal to 38% (db). The value of carbon in the biogas has been calculated equal to $0.44\text{g/g}_{\text{biogas}}$. The carbon content in the leachate from anaerobic digester is 8%.

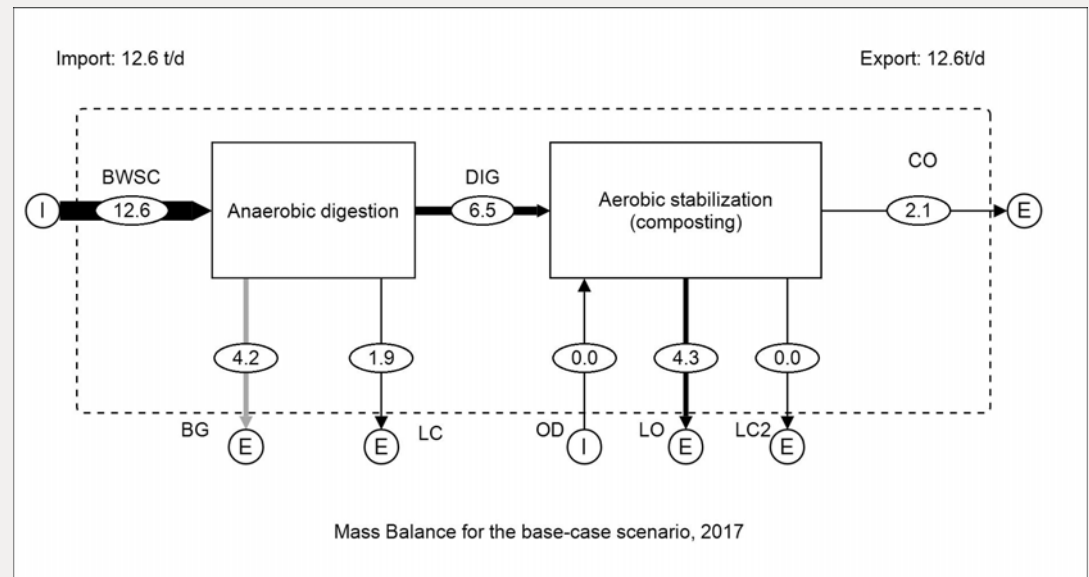


Figure – Carbon mass balance

RESULTS₋₅

The energy balance has been obtained by calculating the feedstock energy of organic flows entering or exiting the sub-processes and associating the formation energies of carbon dioxide and water in the flows containing them (LO). The energy content of leachate flows has been neglected.

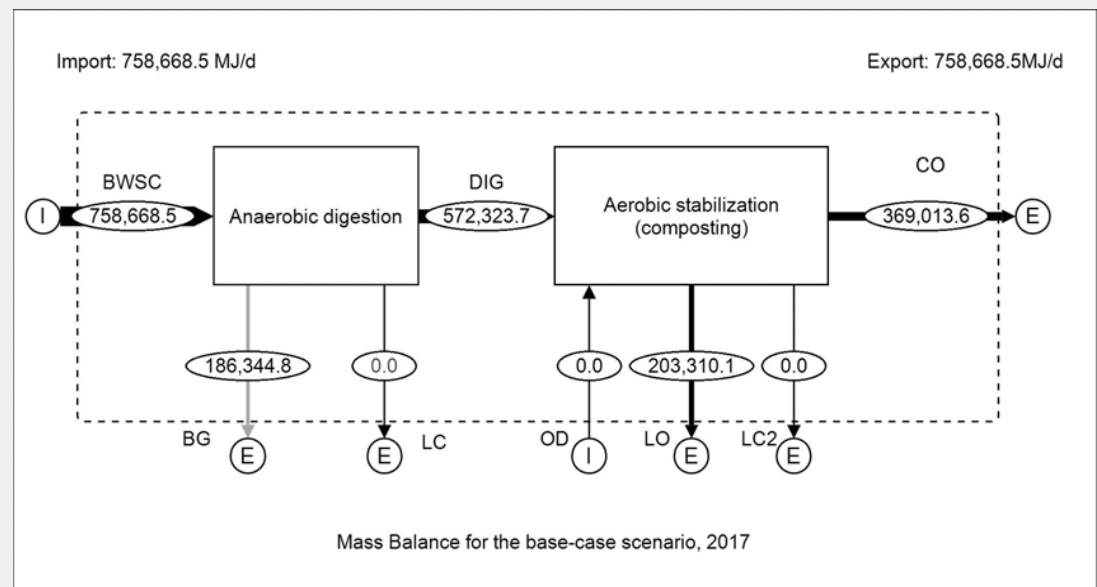


Figure – Feedstock energy balance

RESULTS₋₆

The second scenario is a hypothetical case: in this case, a water flow rate is added to the digestate produced by anaerobic digestion, mixed and fed in a HTC reactor.

Under conditions of moderate temperature (180°C) and high pressure (19bar) the reactions of hydrous pyrolysis undergo.

The ratio R, used to determine the amount of water need for the process has been tested in bench scale reactor fed by digestate. The slurry is then dewatered by centrifugation and thermal drying until a dry hydro-char is obtained. The amount of hydro-char obtained is 28% (dry basis).

The water removed by centrifugation and condensed after drying is recycled in substitution of the fresh water.

This means that the liquid effluent flow rate represents the excess to be disposed for.

RESULTS₇

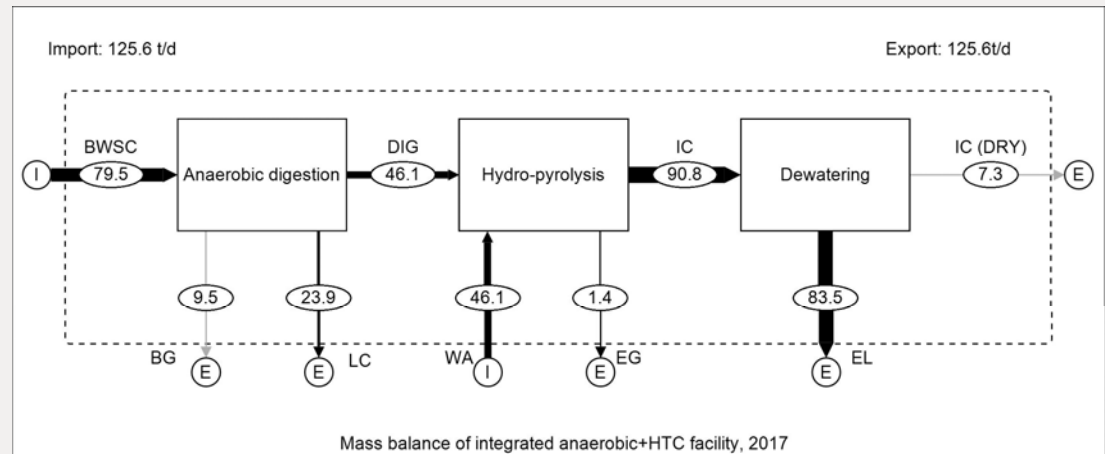


Figure – Total mass balance

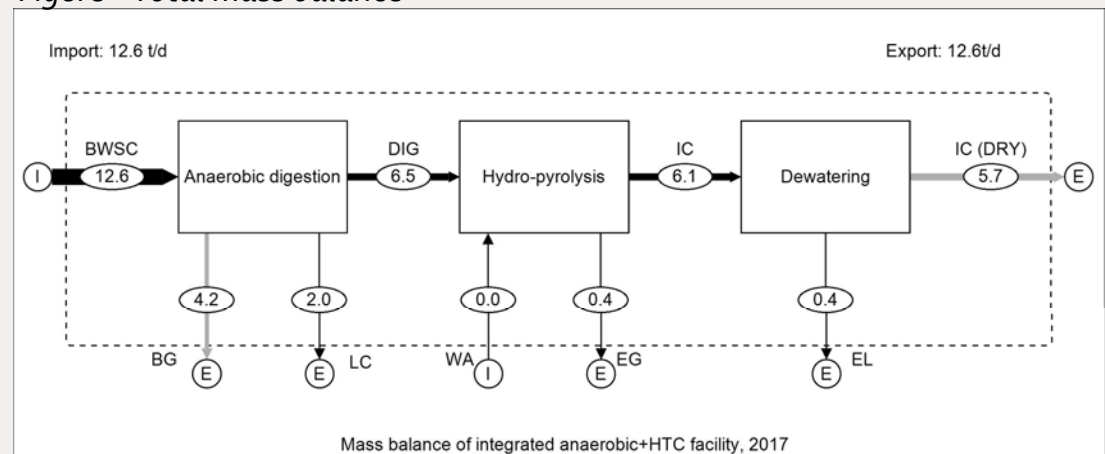


Figure – Carbon mass balance

Discussion

	Base case, t/d	Alternative case, t/d	Difference (altern. – base), %
Carbon recovery	50%	79%	+29%
Products recovery	30% _(dry)	21% _(dry)	-9%
Water consumption	Negligible (moisturizing of compost piles)	Negligible _(make- up to the recycling flow)	-
Energy recovery	73%	98%	+25%
Gas phase emission	20.3 _(theo) – 61 _(real)	1.4	-60%
Liquid emission	33.1	37.4	+4.3%

Conclusion

- The substitution of composting stage with hydrous pyrolysis process allows a series of advantages.
- The calculations indicate that HTC allows a higher energy recovery with a limited environmental burden. In fact, the amount of gas emission is negligible if compared with the real produced by the post-composting stage.
- The liquid effluent production is quite similar for both the cases while the fresh water consumption can be minimized if the recovery and recycling of water inside the process is carried out, in accordance with the best available technologies criteria.
- Apart of the discussed items, it should be also taken into account that the reaction time for HTC is much less than needed for composting (3-6 hours against 90 days) and that the operations are carried out in closed vessels with a total containment of odors losses and fugitive emissions.
- Moreover, the space needed also decreases as a consequence of the high reaction rate.